REMARKS

The Applicant respectfully requests reconsideration and withdrawal of the rejection of claims 21-41 for the reasons below.

In the Office Action of April 23, 2008, claims 21-42 were rejected under 35 U.S.C. §112, first paragraph, as failing to comply with the written description requirement because the limitation "...the wavelength selecting filter includes a mechanism to vary an angle..." is not described in the specification. Adjusting a selected wavelength of a bandpass filter by varying the angle of the filter relative to the incident light is well known in the art; thus, a specific description of how to accomplish this would not be required by a person having ordinary skill in the art in order to make and use the invention.

The Applicants also submit herewith, as evidence, the journal article "Intracavity frequency doubling of a $Nd:YVO_4$ laser pumped by a wavelength-locked laser diode using a transmission-type optical filter" published in *Optics Letters*, June 1, 1994, on pages 810-812. Please note that Figure 2 and the accompanying text, as well as the main body of the article, describe angular dependence of the peak wavelength of the transmission spectrum of a bandpass filter.

In view of the foregoing remarks, and the amendments and remarks in the response submitted March 13, 2008, it is respectfully submitted that the present application is clearly in condition for allowance. An early notice thereof is earnestly solicited.

If, after reviewing these remarks, the Examiner feels there are any issues remaining which must be resolved before the application can be passed to issue, it is respectfully requested that the Examiner contact the undersigned by telephone in order to resolve such issues.

Respectfully submitted,

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Intracavity frequency doubling of a Nd:YVO_4 laser pumped by a wavelength-locked laser diode using a transmission-type optical filter

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We demonstrate that intracavity frequency doubling of Nd:YVO_4 pumped by a laser diode can be stabilized by use of a wavelength-locking system of the laser diode with a transmission-type optical filter in a confocal optical configuration. The wavelength locking of the laser diode to the peak wavelength of the absorption spectrum of Nd:YVO_4 yielded stable green light of 10-mW power for an incident pumping power of 55 mW.

Intracavity second-harmonic generation (SHG) of laser-diode- (LD-) pumped solid-state lasers can supply continuous-wave radiation in the visible and ultraviolet regions.[1-9] Compact green sources have great potential for applications such as high-density optical recording, which require stable output light power of up to several tens of milliwatts. Recently several compact green light sources have been demonstrated, and recording and playback experiments in magneto-optical disk devices have been implemented.[10] Efficient intracavity SHG in $KTiOPO_4$ (KTP) has been demonstrated for a Nd:YVO_4 laser pumped by a single-longitudinal-mode LD.[7-9] In a LD-pumped solid-state laser, stabilizing the LD wavelength to the peak wavelength of the absorption spectrum of the laser material is essential for stable green light generation. We previously demonstrated locking of the LD wavelength with an optical feedback system, wherein the emitted light from the LD was collimated to illuminate a reflection-type diffraction grating and the first-order diffracted beam from the grating was fed back to the active region of the LD.[11]

In this Letter we propose a new optical feedback system to attain highly efficient and stable green light, in which a bandpass optical filter with a narrow transmission bandwidth and high transmittance is inserted into the confocal optical configuration consisting of the front facet of the LD and the reflecting confocal facet of the Nd:YVO_4 laser. A unique advantage of this confocal optical system is that the front facet of the LD is coaxially imaged onto the confocal plane of the Nd:YVO_4 laser, and therefore the optical feedback condition is stably maintained even in the presence of tilt of the reflecting plane.[12]

Figure 1 shows a schematic diagram of an intracavity SHG device. The wavelength-locking system employs a commercially available transmission-type bandpass optical filter with multilayer dielectric coatings on a 0.5-mm-thick plate. A narrow-stripe single-longitudinal-mode LD was used in the experiment. The reflection coating of 2% was formed on the front facet of the LD. The collimated light beam passed through the filter and was focused on the input facet of Nd:YVO_4. The front facet of the LD and the input facet of Nd:YVO_4 were located on the confocal planes. The reflected light beam from Nd:YVO_4 was fed back to the active region of the LD. In this confocal optical configuration, if no wavelength selective optics were used, as in conventional configurations, the reflected light from the focal point on the Nd:YVO_4 would cause multimode oscillation and mode hopping of the LD. In the proposed system, however, the light beam is transmitted through a filter with a narrow spectrum bandwidth in forward and backward paths through the confocal optical system, and therefore stable locking of the longitudinal mode of the LD can be attained in a system with wide mechanical tolerances.[12] The transmittance of the filter was greater than 86%, and the FWHM spectrum bandwidth was less than 0.6 nm. The effective bandwidth was 0.4 nm because the feedback light was transmitted twice through the filter. The central wavelength of the transmission-type filter was shifted as it was tilted from normal to oblique incidence. The angular dependence of the bandpass optical filter was smaller than that in the grating feedback system.[11] In Fig. 2 the solid curve indicates the angular dependence of the peak wavelength at the transmission spectrum of the filter. The horizontal axis shows the angle (θ) between the plane normal to the filter and the optical axis, and the vertical axis is the wavelength at the peak transmittance. The angular dependence was 0.9 nm/deg for $\theta = 10°$ and

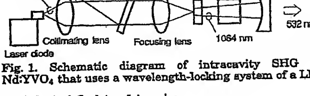

Fig. 1. Schematic diagram of intracavity SHG of Nd:YVO_4 that uses a wavelength-locking system of a LD.

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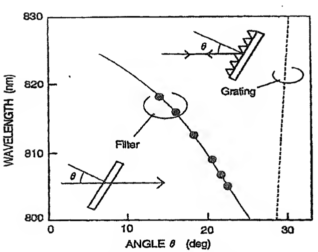

Fig. 2. Angular dependence of the peak wavelength of the transmission spectrum of the filter compared with the angular dependence of the feedback wavelength from the grating. The solid curve shows the characteristic of the filter, and the dotted curve shows the characteristic of the grating feedback optics. The dots show the tuning characteristic of the locked wavelength.

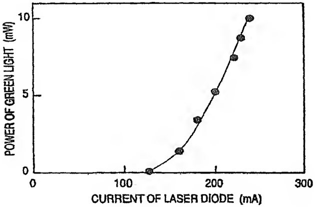

Fig. 3. Output power of green light as a function of the LD input current.

1.5 nm/deg for $\theta = 20°$. The dotted curve shows for comparison the relationship between the setting angle (θ) of the grating and the tuned wavelength of the LD. The angular dependence was 25 nm/deg when the light beam from the LD was collimated by an objective lens of N.A. = 0.5 and fed back by a 1200-groove/mm grating. Thus an optical feedback system based on a transmission-type filter presents a stabler wavelength-locking system for use as a pumping source of solid-state lasers. The in-line-type construction of the confocal optics with a transmission-type filter is superior to the grating feedback optical configuration for minimizing the size of the optical system.

In this experiment a $Nd:YVO_4$ laser with a Nd^{3+} concentration of 3 at.% was employed. The input facet was coated with a reflectivity of more than 99% at 532 nm, more than 99.9% at 1064 nm, and 4.4% at 810 nm. The cavity consisted of the input facet of $Nd:YVO_4$ laser and the output mirror, and the fundamental wave (1064 nm) was converted into green light (532 nm) by a 5-mm-thick KTP crystal. The optical filter provided the feedback light of the selected wavelength to the LD by adjustment of the angle between the light beam and the filter. The selected light was amplified in the active region of the LD and stably locked. The distance between the LD and the $Nd:YVO_4$ laser in this setup was 20 cm. When the angle between the collimated beam axis and the filter was changed, the wavelength of the LD could be tuned over the range from 805 to 818 nm. The dots in Fig. 2 show the tuning characteristic of the locked wavelength of the LD. This indicates that the LD wavelength can be locked in the desired narrow-spectrum bandwidth even though the temperature and the input current of the LD fluctuate. The longitudinal mode of the LD was locked to the peak wavelength (809 nm) of the absorption spectrum of $Nd:YVO_4$ for $\theta = 20.4°$, and efficient pumping was realized. Figure 3 shows output power of green light as a function of the driving current to the LD. Continuous-wave green light of 10-mW power was generated for 55 mW of LD pumping power.

The relative intensity noise of the green light source was less than −130 dB/Hz in the frequency region higher than 2 MHz. In the frequency region less than 2 MHz, however, the green light incidentally suffered from serious noise that was caused by the mode competition of the LD. Greater suppression of the side mode in the longitudinal mode of the LD was achieved as the distance between the LD and the $Nd:YVO_4$ laser was shortened to less than 20 mm. This could lead to lower noise in the frequency region less than 2 MHz as well as in the higher spectrum. The noise dependence on the length between the confocal planes is being investigated in detail.

In conclusion, we have demonstrated that intracavity SHG of a LD-pumped $Nd:YVO_4$ laser can be stabilized by use of a wavelength-locking method with a transmission-type optical bandpass filter. The stable wavelength locking of the LD to the peak wavelength of the absorption spectrum of $Nd:YVO_4$ yielded 10-mW green light for an incident pumping power of 55 mW.

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